A 2D-Optical Scanner Actuated by PZT Film Deposited by Arc Discharged Reactive Ion-Plating (ADRIP) Method

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ABSTRACT

We report a MEMS 2D optical scanner with a powerful thin film piezoelectric PZT actuators prepared by the Arc Discharged Reactive Ion-Plating (ADRIP) method. Two orthogonal pairs of bimorph actuators are used to compose a double-gimbal mirror structure. Novel design of suspension/interconnection has been developed to supply driving voltages to the inner actuators. A mirror of relatively large size (1 mm x 2 mm) has been successfully scanned two-dimensionally with optical 23 degrees (4.3 kHz for X scan) by 52 degrees (90.3 Hz for Y-scan) at low driving voltages of typical 10~20 Vac with 5 Vdc offset.

Keywords: 2D-optical scanner, scanning angle, PZT, arc discharge reactive ion plating, ADRIP

1. INTORODUCTION

Optical MEMS technology has opened up a new architecture of projection displays for personal digital assistant devices, wearable computers, and automobile applications. For creating projected images of high-resolution both spatially and temporally, 2D optical scanners of wide scan angle and large scan-speed contrast are needed. However, most electrostatic actuators have difficulty in doing this with low drive voltages due to small output force.

We have developed a new processing technique called Arc Discharged Reactive Ion-Plating (ADRIP) to produce PZT film of excellent piezoelectric characteristics [1,2]. In this paper, we report application of ADRIP-processed PZT film for driving MEMS 2D optical scanners.

2. PIEZO SCANNER MECHANISM

Figure 1 shows a principle of generating rotational motion of a mirror by using piezoelectric bimorph actuator beams. One of the beams deflects downward with an applied voltage, while the other one bends upward with a voltage of the reverse polarity. These bending motions are converted into an angular motion of the torsion bar attached in the middle part.

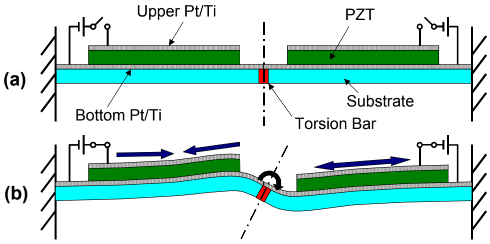

Fig. 1 Mechanism of generating rotational motion by using a pair of piezoelectric bimorph actuator beams

Figure 2 illustrates the design of the piezoelectric 2D scanner. A double-gimbal structure is used to two-dimensionally tilt the ellipse mirror (1 mm x 2 mm) located in the middle part. The inner set of short torsion bars and small U-shaped bimorph actuators is used for the mirror's fast motion around the X-axis, while slow scan around the Y-axis is made by using the outer set of long torsion bars and larger U-shape actuators. Additional mass is used on the inner-ring for the slow-scan mechanism and to increase the contrast of the fast and slow scan rates.

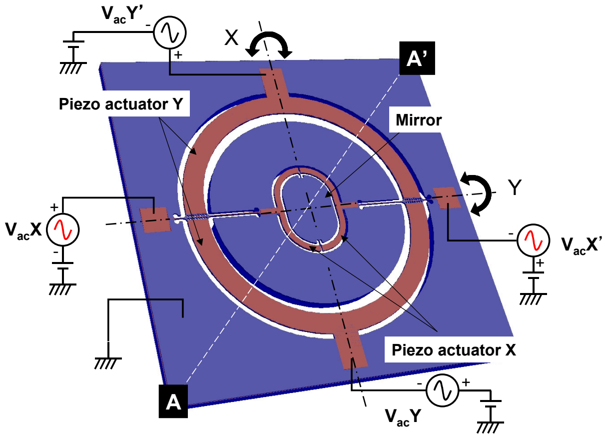

Fig. 2 Schematic view of piezoelectric 2D-scanner.

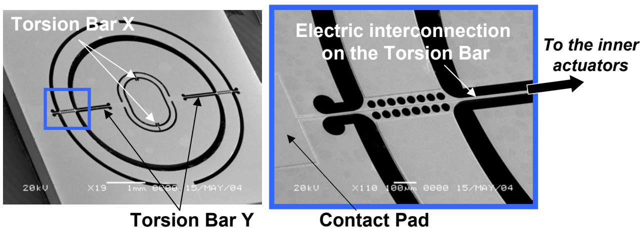

Fig. 3 Scanning electron micrograph of fabricated piezoelectric scanner.

As shown in Fig. 3, drive voltages to the outer actuators are applied directly to the anchoring pads. On the other hands, voltages to the inner actuators are given through the electric interconnection on the torsion bar Y (16 um wide and 920 um long, 20 um SOI thick), which is mechanically connected to the chip frame.

3. FABRICATION

Figure 4 shows the fabrication steps of the piezoelectric scanner (on the crosssection A-A' in Fig. 2). In step-1, all the layers for the piezoelectric actuator are sequentially made: (from the bottom to top) a thermally-grown silicon oxide layer (500 nm) for insulator, sputtered titanium (50 nm) and platinum (150 nm) for bottom electrode, an ADRIP-processed PZT film (2 um) for piezoelectric drive, and metal layers for top electrode (by the same process condition as the bottom one). In step-2, these layers are patterned into piezo-actuator structures by two photolithography steps and reactive ion etching. In step-3, the SOI layer (20 um) is etched by DRIE to make the scanner structures. The backside of the SOI wafer is then etched to the buried oxide by two-step DRIE [3]. A part of the silicon substrate is left by 200-um in height on the backside of the inner ring to increase the mass for slow scan around the Y-axis.

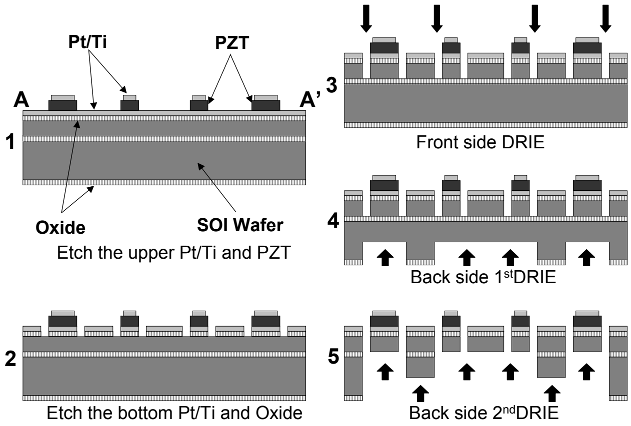

Fig. 4 Fabrication steps of piezoelectric scanner (on the crosssection A-A' in Fig. 2)

4. RESULTS 2D SCAN

Figure 5 shows frequency response of scan angles. Resonant frequency around the fast (X) axis was 4.3 kHz with excitation voltage of 3 Vac, while that of the slow (Y) axis was 90.3 Hz; frequency ratio of approximately 47 was obtained. Scan angle at resonance was found to be fairly linear with applied AC voltage as shown in Fig. 6. Figure 7 shows 2D-scanned laser beam image projected on a screen. Large optical angles was obtained; 23 degrees the fast (X) axis with 20 Vac + 5Vdc, and 52 degrees for the slow (Y) axis with 10 Vac + 5 Vdc. Overall frequency range can be increased by using a thicker SOI layer, which is under development for improving image quality.

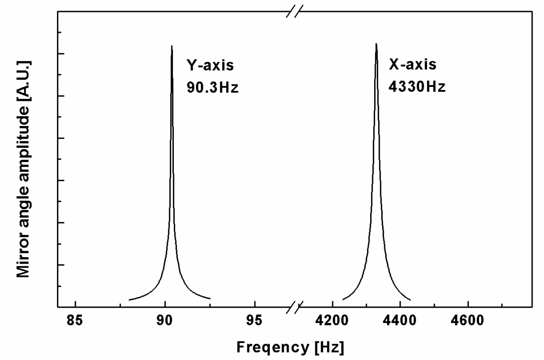

Fig. 5 Frequency response of mirror angles around fast- and slow-axes.

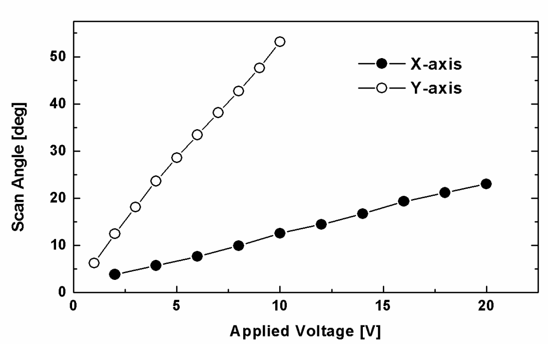

Fig. 6 Scan angles (X and Y) at resonance as a function of excitation AC voltage.

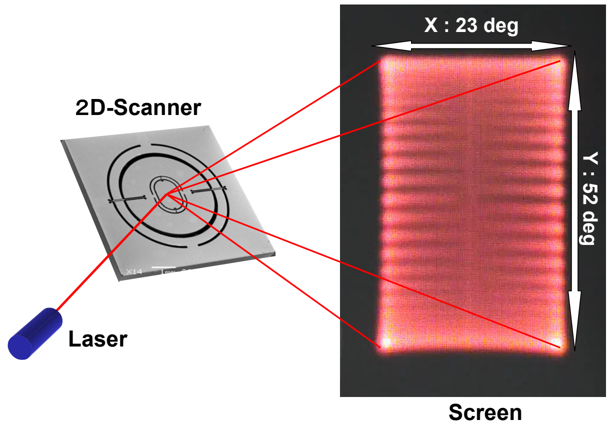

Fig. 7 Projected laser beam image scanned at resonance.

REFFERENCES

[1] Masahiro Akamatsu, Masanao Tani, Yoshiaki Yasuda, "Fast Deposition of Lead-Zirconate-Titanate Thick Films by Arc Discharged Reactive Ion-Plating Method," *Jpn. J. Appl. Phys.* 41 (2002) pp. 6976-6979

[2] Takashi Iijima, Hirofumi Matsuda, Sachiko Ito, Masanao Tani, Masahiro Akamatsu and Yoshiaki Yasuda, "Texture-Control of Lead Zirconate Titanate Films for Actuator Applications", *SPIE's Int. Symp. on Photonics Fabrication Europe, Transducing Materials and Devices*, December 1, 2002, Brugge.

[3] M. Mita, Y. Mita, H. Toshiyoshi and H. Fujita, "Delay-Masking Process for Silicon Three-Dimensional Bulk Structures" *Trans. IEE Japan*, May (1999), p. 310.